EFFECT OF ELECTRICAL DISCHARGE MACHINING PROCESS PARAMETER ON SURFACE TOPOGRAHY

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Report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Mechanical Engineering

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This paper was developed the mathematical modelling of EDM process parameters to predict the surface roughness of Ti-6Al-4V. The process is used in situations where intricate complex shapes need to be machined in very hard materials such as titanium alloy. However, the process generates surfaces that have poor properties such as high surface roughness, slow machining removal rate and moderate electrode wear rate. These properties vary with different levels of the main process parameters such as peak current, servo voltage, pulse on-time and pulse off-time. The aim of this paper is to perform experimental work that has been done in order to explore the relationships between input and output parameters. Response surface design is used because the input and output parameter were suspect have curvature relationships. A mathematical model develops base on response surface method. The significant coefficients were obtained by performing Analysis of Variance (ANOVA) at 95% level of significance. Adequacy test was carried out to check the fitting of the models. It found that the peak current, servo voltage and pulse on time are significant in material removal rate and surface roughness. Peak current has the greater impact on surface roughness and material removal rate. Finally, a metallurgical microscope is carried to observe the surface topography.

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ABSTRACT

Tujuan untuk project ini adalah mengembangkan model metamatik bagi EDM proses parameter untuk memprediksi kekasaran permukaan. EDM proses biasanya digunakan dalam situasi di mana bentuk kompleks rumit perlu memotong bahan yang sangat keras seperti gabungan titanium. Namun, proses tersebut menghasilkan permukaan yang memiliki sifat buruk seperti kekasaran permukaan tinggi, tahap enjin removal yang lambat dan laju kehausan elektrod. Property ini berbeza dengan tahap yang berbeza dari parameter proses utama seperti tegangan arus puncak, servo, pulsa pada waktu dan pulsa off-bila masa. Tujuan makalah ini adalah untuk melakukan kerja eksperimen yang telah dilakukan untuk mengeksplorasi hubungan antara parameter input dan output. Respon design surface digunakan kerana parameter input dan output disyaki mempunyai hubungan kelengkungan. Tiga model matematik mengembangkan pangkalan pada kaedah response surface method. Pekali signifikan diperolehi dengan melakukan Analisis Varian (ANOVA) pada peringkat 95% signifikansi. Adequate test dilakukan untuk memeriksa pemasangan model. Didapati bahawa puncak saat ini, voltan servo dan pulsa pada waktu yang signifikan pada angka removal material dan kekasaran permukaan. Puncak saat ini mempunyai kesan yang lebih besar pada kekasaran permukaan dan tahap bahan penghapusan. Akhirnya, mikroskop metalurgi dilakukan untuk mengamati topografi permukaan.

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LIST OF SYMBOLS

A	Ampere
V	Voltage
ms^{-1}	Meter per second
μ	Micro
W_{w1}	Weight of work piece after machining
W_{w2}	Weight of work piece before machining
W_e	Weight difference of electrode
W_1	Weight of electrode after machining
W_2	Weight of electrode before machining
T	Time
ρ_e	Density of copper

LIST OF ABBREVIATIONS

EDM	Electric Discharge Machine
S_a	Surface roughness
EWR	Electrode Wear Rate
MRR	Material Removal Rate
RSM	Response Surface Methodology
CCD	Central Composite Design
MMCs	Metal Matrix Composites
Ti_6Al_4V	Titanium alloy Grade 5
IP	Peak Current
SV	Servo voltage
ON	Pulse on time
OFF	Pulse off time
DOE	Design of Experiment
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nowadays, the application of advanced machining processes in manufacturing industry is become more important for company to produce the better or good product the better or good products that happened such as in machining high hardness and the strength of the material, creating complex shape, obtains the better surface finish and dimensional tolerances. Electric discharge machining (EDM) is one of the most popular non-traditional material removal processes and has became a basic machining method for the manufacturing industries of aerospace, automotive, nuclear, medical and die-mold production. The theory of the process was established by a Soviet scientist, Lazarenko, in the middle of 1940s. They invented the relaxation circuit and a simple servo controller tool that helped to maintain the gap width between the tool and the work piece. This reduced arcing and made EDM machining more profitable and produced first EDM machine in 1950s. Major development of EDM was observed when computer numerical control systems were applied for the machine tool industry. Thus, the EDM process became automatic and unattended machining method . (Kiyak and Kakir, 2007)

The process uses thermal energy to generate heat that melts and vaporizes the work piece by ionization within the dielectric medium. The electrical discharges generate impulsive pressure by dielectric explosion to remove the melted material. Thus, the amount of removed material can be effectively controlled to produce complex and precise machine components. However, the melted material is flushed away incompletely and the remaining material resolidifies to form discharge craters. As a result, machined surface has micro cracks and pores caused by high temperature gradient which reduces surface finish quality. There have been many published studies considering surface finish of machined materials by EDM. It was noticed that various machining parameters influenced surface roughness and setting possible combination of these parameters was difficult to produce optimum surface quality. The influences of some machining parameters such as pulsed current, pulse time, pulse pause time, voltage, dielectric liquid pressure, electrode material. (Kiyak and Kakir, 2007).

Titanium has been recognized as an element (Symbol Ti; atomic number 22; and atomic weight 47.9) for at least 200 years. However, commercial production of titanium did not begin until the 1950’s. At that time, titanium was importance because it has very high strength and light weight, extraordinary to corrosion resistance. These characteristics made it as efficient as metal for critical, high-performance aircraft, such as jet engine and airframe components. The worldwide production of this originally exotic, “Space Age” metal and its alloys has since grown to more than 50 million pounds annually. Increased metal sponge and mill product production capacity and efficiency, improved manufacturing technologies, a vastly expanded market base and demand have dramatically lowered the price of titanium products. Today, titanium alloys are common, readily available engineered metals that compete directly with stainless and specialty steels, copper alloys, nickel based alloys and composites. As the ninth most abundant element in the Earth’s Crust and fourth most abundant structural metal, the current worldwide supply of feedstock ore for producing titanium metal is virtually unlimited. Significant unused worldwide sponge, melting and processing capacity for titanium can accommodate continued growth into new, high-volume applications. In addition to its attractive high strength-to-density characteristics for aerospace use, titanium’s exceptional corrosion resistance derived from its protective oxide film has motivated extensive application in seawater, marine, brine and aggressive industrial chemical service over the past fifty years. Today, titanium and its alloys are extensively used for military applications, aircraft, spacecraft, medical devices, connection rods on expensive sports cars and some premium sports equipment and consumer electronics. Auto manufacturers Porsche and Ferrari also use titanium alloys in engine components due to its durable properties in these high stress engine environments.

In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The method was introduced by Box and Wilson in 1951. (Bhattacharyya et al. 2007). A sequence of designed experiments generated by RSM use to obtain an optimize response. Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process.

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1.2 PROBLEM STATEMENT

Traditionally electric discharge machining process carried out by relying heavily on the operator's experience or conservative technological data provided by the EDM equipment manufacturers, which produced inconsistent machining performance. The parameter settings given by the manufacturers are only applicable for the common steel grades. The settings for new materials such as titanium alloys, aluminum alloys, special steels, advanced ceramics and metal matrix composites (MMCs) have to be further optimized experimentally. Optimization of the EDM process often proves to be difficult task owing to the many regulating machining variables. A single parameter change will influence the process in a complex way. Thus the various factors affecting the process have to be understood in order to determine the trends of the process variation. The selection of best combination of the process parameters for an optimal surface roughness involves analytical and statistical methods. Once the optimum parameter is obtain, it reduces the machining cost and improved product's quality.

1.3 OBJECTIVES

The objectives of this project are as following:

1. To develop mathematical models for predicting the material removal rate, electrode wear rate and surface roughness.
2. To optimize the machining parameters using RSM method.
3. In addition, this study was generated more knowledge and experience during operating EDM.

1.4 SCOPES

This study mainly focuses on machining of titanium alloys, which will be carried out in die-sinking EDM. MINITAB software is using to design the experiment by response surface design. Response surface design was used because its suspect has curvature relationships between input and output parameter. The machining (input) parameters selected in this project were peak current, servo voltage, pulse on time, pulse off time; output parameter were material removal rate, electrode wear rate and surface roughness. Three mathematical models were develops by using response surface method. Adequate test is necessary to make sure the model is fit. Next, the surface topography was observed by using metallurgical microscope and integrated software.

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1.5 ORGANIZATION OF REPORT

Chapter 1 focused on the introduction of EDM die-sinker machine, titanium alloy grade 5 and Response Surface Method. Chapter 2 was about literature review from the previous study. Chapter 3 presents the methodology on the progress. Chapter 4 presents the result and discussion and chapter 5 summarize the finding for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter contents the properties and composition of Ti_6Al_4V. Besides, it reviews the history and machining concern of die-sinking EDM. Response surface method used to develop the mathematical models so can predict the output. In addition, the previous study of relationship between input and output parameters.

2.2 TITANIUM ALLOYS

Titanium alloys are replacing traditional aluminum alloys in many aerospace applications because of their unique high strength to weight ratio that is maintained at elevated temperatures and their exceptional corrosion resistance. The demand of titanium alloy was predicted increase gradually at the following years. Titanium alloy is more difficult to cut than common steel alloys and hence titanium is considered a difficult-to-machine material. The main concern of titanium alloys is the difficult to cut. Their low thermal conductivity leads to high cutting temperatures, and their high chemical reactivity with many tool materials leads to strong adhesion between the tool and work material. These two factors lead to rapid tool wear during machining of titanium alloys, which in turn increases the manufacturing cost. Therefore, unconventional machining, Electrical Discharge Machine is recommended.

Titanium Alloys, Ti_6Al_4V, sometimes called titanium grade 5 or VT6, is classified as alpha-beta alloy. Alpha and Beta Alloys, which are metastable and usually contains some combination of both alpha and beta stabilizers, and which can be heat treated. Generally, beta-phase titanium is stronger yet less ductile and alpha-phase titanium is more ductile. Alpha-beta-phase titanium has a mechanical property which is in between both. It is the most commonly used alloy because over 70% of all alloy grades melted are a sub-grade of Ti_6Al_4V. Table 2.1 and Table 2.2 show the composition and characteristic of Titanium Ti_6Al_4V.

Table 2.1: The chemical composition by weight for Ti_6Al_4V

Chemical composition	**C**	**Fe**	**N_2**	**O_2**	**Al**	**V**	**H_2**	**Ti**
Wt(%)	< 0.08	< 0.25	< 0.05	< 0.2	5.5-6.76	3.5-4.5	< 0.0125	rest

Table 2.2: Typical physical properties for Ti6Al4V

Property	**Typical Value**
Density g/cm^3	4.42
Melting Range ^{0}c	1649
Specific Heat J/kg.^{o}C	560
Volume Electric Resistivity ohm.cm	170
Thermal Conductivity W/m.k	7.2
Tensile Strength MPa	897-1000
0.2% Proof Stress Mpa	828-910
Elastic Modulus GPa	114
Hardness Rockwell C	36

2.3 Die-Sinking EDM

Non-conventional machining processes such as the electrode discharge machining (EDM) are being widely used to machine hard tool and die materials used in the industries. Materials of any hardness can be cut as long as the material can conduct electricity. Many complex shapes can be reproduced in the workpiece. A small amount of material, up to 15% is expelled violently from the surface melt and the remaining liquid resolidifies. The recast structure is typically very fine grained and hard, and may be alloyed with carbon from the cracked dielectric or with material transferred from the tool. Many mould makers use two electrodes, one for roughing operations and another one for the finishing operation. This process finishes the surface and produces a thin plastically deformed layer at the surface. Unfortunately even though EDM technology has proved to be very efficient in machining out complex shapes and also to machine very hard materials, there are several problems that are associated with this machining method. The main problem is the formation of a ‘recast’ white layer, which is very hard and contains many imperfections such as cracks, micro cracks and high tensile residual stresses. These features are undesirable in most cases since early failure of the component might result. The severity of the damage in the recast layer depends on the machining conditions. A roughing condition will entail fast machining (high productivity) operation but severe damage and high surface roughness. Thus a suitable process parameter is important so as to improve the productivity of this process and at the same time getting an optimum surface integrity.

2.4 MACHINING PARAMETER

Basically, there have two types of parameters which were input parameters and output parameters. Input parameters are help to distribute the output parameters, in order words, they are interrelated. Various input result various output. One of the objectives of this study is study the relationship between input and output. After analysis, then get a set of optimum parameters. In this study, the input parameters were peak current, pulse-on-time, pulse-off-time and servo voltage. These input parameters were various for the experiments. Others parameters were remains constant at these experiments .Constant parameters were included polarity, servo speed, flushing pressure, main power supply, jump-up time, jump-down machining time, jump speed and so on. Usually, constant parameter takes a least effect on the output parameter so there was no investigation needed. The output parameters were material removal rates, electrode wear rate and surface roughness. Material removal rate is the rate of the Ti_6Al_4V removed per second. Electrode wear rate is the rate of copper electrode removed per second. Surface roughness is the measure if the finer surface irregularities in the surface texture. These are the result of the manufacturing process employed to create the surface. Surface roughness Ra is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micro inches or micro meters Table 2.3 shows all the machining parameters.

Table 2.3: Machining parameter

Parameter	**Function**
PL	Polarity
ON	Electric discharge time
OFF	Electric discharge off time
IP	Electric discharge peak current
SV	Servo voltage
S	Servo speed
UP	Jump-up time
DN	Jump-down machining time
JS	Jump speed
LNS	Loran shape
STEP	Loran orbiting motion distance on one side
V	Main supply voltage
HP	Auxiliary power supply current control, pulse control, capacitor, selection
PP	PIKADEN pulse, shutoff circuit control
C	Capacitor
ALV	Arc detection level
OC	ON pulse control
LF	OFF pulse control, HS servo
JM	Jump mode
LS	Loren speed and direction
LNM	Loran mode

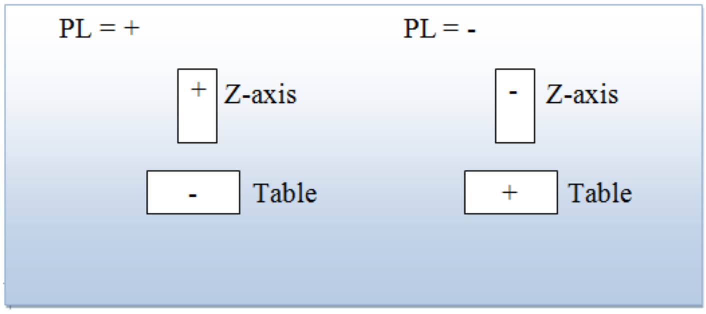

Figure 2.1: Polarity

Polarity, PL, determines electric polarity of the electrode and work piece. Choose ‘positive’ and ‘negative’ for the z-axis. Usually z-axis was referred to electrode. Polarity selection depending on the machining conditions and the material combination of the work piece and the electrode, it may be necessary to change the polarity. If wrong polarity is set, good machining performance may not be obtained. Figure 2.1 show the polarity.

Pulse on-time specifies the duration of an electric discharge and determines the electric discharge pulse control system. In others words, it was the duration of time the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on time. This energy is controlled by the peak current and the length of the on-time.

Pulse off-time specifies the duration of a stop between electric discharge pulses off. It is the duration of time between the sparks. This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Therefore, the performance will more stable for the long off-time.

Peak current specifies the peak current for EDM. Peak current is the sum of the main electric discharge current and the SVC electric discharge current. This is an important parameter that determines the machining performance such as machining speed, surface roughness, electrode wear, or discharge gap, in combination of the time.

Servo voltage specifies a reference voltage for servo motions to keep gap constant. This servo motion control is performed in accordance with gap voltage .Fluctuation relative to servo voltage when gap voltage is higher than servo voltage, the electrode advances for machining; when it is lower, the electrode retracts to open the gap.

2.5 RESPONSE SURFACE METHODOLOGY

Response surface methodology is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. When higher order polynomial model is used, the accuracy will be increase but generally it up to second order only. To provide some context, there is good commercial software available to help with designing and analyzing response surface experiments. The most popular include Design-Expert, Minitab and many others.

Response-surface method involve some unique experimental-design issues, due to the emphasis on iterative experimentation and the need for relatively sparse designs that can be built-up piece-by-piece according to the evolving needs of the experimenter. Besides, response-surface analysis is not simply regression problem, there are several intricacies in this analysis and how it is commonly used that are enough different from routine regression problems that some special help is warranted. These intricacies include the common use of coded predictor variables; the assessment of the fit; the different follow-up analyses that are used depending on that type of model is fitted, as well as the outcome of the analysis; and the importance of visualizing the response surface. Below is a general overview of response-surface method.

1. Provides functions and data types that provide for the coding and decoding of factor levels, since appropriate coding is an important element of response-surface analysis
2. Provides functions for generating standard designs.
3. Extends R's lm function to simplify the specification of standard response-surface models, and provide appropriate summaries.
4. Provides means of visualizing a fitted response surface.
5. Provides guidance for further experimentation.

Generally, DOE is used to design a set of experiment by control the variation. In the design of experiments, the experimenter is often interested in the effect of some process or intervention on some objects which may be people, parts of people, groups of people, plants, animals, etc. Response surface designs are types of Experimental Design that suspect that has the curvature response between input and output. The design matrix originally used included the limits of the factor settings available to run the process. In other words, response surface designs achieve this by using a quadratic regression equation rather than the linear form of the regression equation used in factorial designs. (Anderson and Whitcomb. 2005.)

Central composite designs consist of factorial points, axial points and central point. Central composite designs are often recommended when the design plan calls for sequential experimentation because these designs can incorporate information from a properly planned factorial experiment. The factorial and centre points may serve as a preliminary stage where you can fit a first-order (linear) model, but still provide evidence regarding the importance of a second-order contribution or curvature (Anderson and Whitcomb. 2005). Orthogonally blocked designs allow for model terms and block effects to be estimated independently and minimize the variation in the regression coefficients. Rotatable designs provide the desirable property of constant prediction variance at all points that are equidistant from the design centre, thus improving the quality of prediction.

2.6 ANALYSIS OF VARIANCE

Analysis of variance (ANOVA) is a powerful statistical tool. It has the function that quantifying interactions between independent variables and at the same time to determine their impact on the predicted variables. Besides that, the treatment data must be normally distributed. ANOVA table lists the sources of variation, their degrees of freedom, the total sum of squares, and the mean squares. The analysis of variance table also includes the *F*-statistics and *P*-values. Use these to determine whether the predictors or factors are significantly related to the response (Healey and Prus 2009). *P*-value ranges from zero to one. *P*-value has the function that determines the probability to rejecting the null hypothesis in hypothesis test. When the *P*-values is higher that the α-values, its mean significant. The smaller *P*-value has higher accuracy. Because of their indispensable role in hypothesis testing, *P*-values are used in many areas of statistics including basic statistics, linear models, reliability, and multivariate analysis among many others. The key is to understand what the null and alternate hypotheses represent in each test and then use the *P*-value to aid in your decision to reject the null. (Healey and Prus 2009)

Lack-of-fit used in regression and DOE, lack-of-fit tests assess the fit of your model. If the *P*-value is less than your selected α-level, evidence exists that your model does not accurately fit the data. You may need to add terms or transform your data to more accurately model the data. Minitab calculates two types of lack-of-fit tests (Ott and Longnecker 2008).

R-square is percentage of response variable variation that is explained by its relationship with one or more predictor variables. In general, the higher the R^2, the better the model fits your data. R^2 is always between 0 and 100%. It is also known as the coefficient of determination or multiple determinations in multiple regressions (Ott and Longnecker 2008). Used in regression analysis to indicate how well the model predicts responses for new observations, whereas R^2 indicates how well the model fits your data. Predicted R^2 can prevent over fitting the model and can be more useful than adjusted R^2 for comparing models because it is calculated using observations not included in model estimation. Over fitting refers to models that appear to explain the relationship between the predictor and response variables for the data set used for model calculation but fail to provide valid predictions for new observations. Percentage of response variable variation that is explained by its relationship with one or more predictor variables, adjusted for the number of predictors in the model. This adjustment is important because the R^2 for any model will always increase when a new term is added. A model with more terms may appear to have a better fit simply because it has more terms. However, some increases in R^2 may be due to chance alone.

The adjusted R^2 is a useful tool for comparing the explanatory power of models with different numbers of predictors. The adjusted R^2 will increase only if the new term improves the model more than would be expected by chance. It will decrease when a predictor improves the model less than expected by chance. (Ott and Longnecker. 2008)

2.7 RELATIONSHIP BETWEEN PARAMETERS

For sure, there were relationships between input and output parameters. If second order of RSM was used, it can generate up to linear, interaction, or square relations between parameters. This study was indicated the relationship between peak current, servo voltage, pulse on-time, pulse off-time with material removal rate, electrode removal rate and surface roughness.